

**Listing of Claims:**

This listing of claims replaces all prior versions, and listings, of claims.

1-46. (Cancelled)

47. (Previously presented) An apparatus suitable for controlling the size and the phase of an electromagnetic beam, the apparatus comprising:

a. a substrate; and

b. a vertically Graded Refractive index (vGRIN) multilayer structure deposited on the substrate, the multilayer structure including a vGRIN film and a curved input sidewall and a curved output sidewalls, the input sidewall being a sidewall on which the electromagnetic beam is incident on the apparatus, the output sidewall being a sidewall through which the electromagnetic beam leaves the apparatus, wherein the apparatus is used to independently control a vertical focusing and a horizontal focusing of the electromagnetic beam.

48. (Previously presented) The apparatus as recited in claim 47 wherein the curved input sidewall and the curved output sidewall are fabricated by photolithography and etching with an etching mask comprising:

a. at least one of a metal layer and a polysilicon layer deposited on the vGRIN film; and

b. a photoresist layer spin-coated on the at least one of the metal and the polysilicon layer.

49. (Previously presented) The apparatus as recited in claim 47 wherein the substrate comprises at least one of a Si, GaAs, InP, AlN, LiNbO<sub>3</sub> and quartz composition.

50. (Previously presented) The apparatus as recited in claim 47 wherein the substrate comprises a glass.

51. (Previously presented) The apparatus as recited in claim 47, further comprising a waveguide operatively coupled to the apparatus, wherein a connection between the apparatus and the waveguide is established using photolithography.

52. (Previously presented) The apparatus as recited in claim 47 wherein the apparatus is fabricated in an array form for multi-channel light coupling into or out of a multi-port photonic chip.

53. (Previously presented) The apparatus as recited in claim 47 wherein the vertical focusing is controlled by varying a thickness of the vGRIN multilayer structure.

54. (Previously presented) The apparatus as recited in claim 47 wherein the horizontal focusing is controlled by varying at least one of a radius of curvature of a surface of the curved input sidewall and a radius of curvature of a surface of the curved output sidewall.

55. (Previously presented) The apparatus as recited in claim 53 wherein the thickness of the vGRIN multilayer structure is varied by etching.

56. (Previously presented) The apparatus as recited in claim 47 wherein a radius of curvature of a surface of the curved input sidewall and a radius of curvature of a surface of the curved output sidewall are varied by etching.

57. (Previously presented) The apparatus as recited in claim 47 wherein the electromagnetic beam leaving the apparatus is a divergent beam when a thickness of the vGRIN multilayer structure is in a range  $((2n-1) \times f / 4)$  and  $(n \times f / 2)$ , where  $f$  is a pitch of the vGRIN film and  $n$  is a natural number.

58. (Previously presented) The apparatus as recited in claim 47 wherein the electromagnetic beam leaving the apparatus is a convergent beam when a

thickness of the vGRIN multilayer structure is in the range and  $(n \times f / 2)$  and  $((2n+1) \times f / 4)$ , where  $f$  is a pitch of the vGRIN film and  $n$  is a natural number.

59. (Previously presented) The apparatus as recited in claim 47, wherein a surface of the curved input sidewall and a surface of the curved output sidewall comprise one of a spherical shape, aspherical shape, cylindrical shape and toric shape.

60. (Withdrawn) The apparatus as recited in claim 59 wherein the surface of the curved input sidewall and the surface of the curved output sidewall have same radii of curvature.

61. (Previously presented) The apparatus as recited in claim 59 wherein the surface of the curved input sidewall and the surface of the curved output sidewall have different radii of curvature.

62. (Withdrawn) The apparatus as recited in claim 59 wherein a radius of curvature of the surface of the curved input sidewall and a radius of curvature of the curved output sidewall are positive.

63. (Withdrawn) The apparatus as recited in claim 59 wherein a radius of curvature of the surface of the curved input sidewall and a radius of curvature of the surface of the curved output sidewall of the input sidewall have same signs.

64. (Previously presented) The apparatus as recited in claim 59 wherein a radius of curvature of the surface of the curved input sidewall and a radius of curvature of the surface of the curved output sidewall of the input sidewall have different signs.

65. (Previously presented) The apparatus as recited in claim 47 wherein a surface of the curved input sidewall and a surface of the curved output sidewall have arbitrary curved shapes.

66. (Previously presented) The apparatus as recited in claim 47 wherein a vertical refractive index profile of the vGRIN film comprises an arbitrary refractive index variation.

67. (Previously presented) The apparatus as recited in claim 47 wherein at least one of the curved input sidewall and the curved output sidewall comprises an anti-reflection coating.

68. (Previously presented) The apparatus as recited in claim 67 wherein the antireflection coating is designed on a basis of at least one of a central refractive index, an average refractive index, and an optimum equivalent index that leads to a maximum electromagnetic wave transmission.

69. (Previously presented) The apparatus as recited in claim 47 wherein the curved input sidewall and the curved output sidewall comprise a three-dimensional curved surface such that a radius of curvature of the curved input sidewall and a radius of curvature of the curved output sidewall diminish with a departure from a vertical central region of the vGRIN film.

70. (Previously presented) The apparatus as recited in claim 47 wherein a Graded Refractive Index distribution of the apparatus is a standard distribution.

71. (Previously presented) The apparatus as recited in claim 47 wherein a Graded Refractive Index distribution of the apparatus is parabolic.

72. (Previously presented) The apparatus as recited in claim 47 wherein the electromagnetic beam leaving the apparatus has at least one of a circular spot size and an elliptical spot size.

73. (Previously presented) The apparatus as recited in claim 47 wherein a wavelength of the electromagnetic wave is in the visible range.

74. (Previously presented) The apparatus as recited in claim 47 wherein a wavelength of the electromagnetic wave is in the Radio Frequency (RF) range or in the TeraHertz range.

75. (Previously presented) The apparatus as recited in claim 64 wherein the radius of the curvature of the surface of the curved input sidewall is positive and the radius of curvature of the surface of the curved output sidewall is negative.